Title: PSI 2018/2019 - Cosmology Review - Lecture 14

Date: Jan 24, 2019 09:00 AM

URL: http://pirsa.org/19010015

Abstract:

Bounding Cosmologies

CMB : background : flat, homog. & isotr.

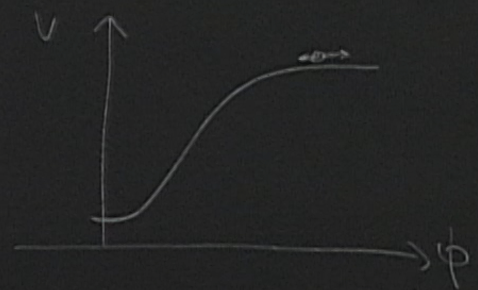
fluct.$^{\underline{ns}}$: nearly sc.-inv.$^{\underline{t}}$, Gaussian

ΛCDM requires particular initial cond.$^{\underline{ns}}$

$\rightarrow$ explain the state of the early univ.$^{\underline{e}}$ dynamically.

Problems of inflation

1. doesn't provide complete history of universe (still have big bang singularity)

2. 

[Gibbons, Turok]

[Penrose]: entropy problem

3. $r = 0.2 \rightarrow r \lesssim 0.1$

4. Eternal Inflation → Measure Problem

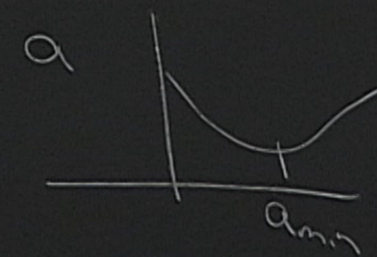
Bouncing Cosmologies Overview

contracting phase $\xrightarrow{\text{bounce}}$ expanding phase

$H = \frac{\dot{a}}{a}$

$H < 0$ $\qquad \dot{H} > 0$ $\qquad H > 0$

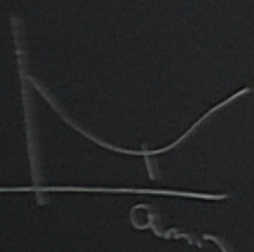
1. Non-sing.^{r} bounce :



flat $k=0$ $\qquad \dot{H} = -$

expanding phase (observable univ.^{s})

$$H > 0$$



flat
$k=0$ $\quad \dot{H} = -\frac{1}{2}(\rho + P) \quad \Rightarrow \rho + P < 0$

$\cancel{NEC}$

$$T_{\mu\nu} n^{\mu} n^{\nu} > 0$$

$$\rho + P > 0$$

$\rho < 0$

$\cancel{\text{NEC}}$

$T_{\mu\nu} n^\mu n^\nu > 0$

$\rho + P > 0$

$\Rightarrow$ ghosts : (sc.) fields w/ -ve kinetic energy

$\rightarrow$ fluct$^{\underline{ns}}$ lower the en. , en. unbounded from below

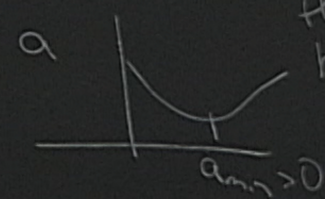
Bouncing Cosmologies Overview

contracting phase $\xrightarrow{\text{bounce}}$ expanding phase (observable univ.$^{\underline{s}}$)

$H = \frac{\dot{a}}{a}$

$H < 0$ $\qquad$ $\dot{H} > 0$ $\qquad$ $H > 0$

1. Non-sing.$^{\underline{r}}$ bounce :



flat $k=0$ $\quad \dot{H} = -\frac{1}{2}(\rho + P) \Rightarrow \rho + P$

2. Sing.$^{\underline{r}}$ bounce : $a \to 0$

The ekpyrotic phase

Friedmann equ.: $3H^2 = \Lambda - \frac{3k}{a^2} + \frac{\rho_{m,0}}{a^3} + \frac{\rho_{r,0}}{a^4} + \frac{\rho_{\sigma,0}}{a^6} + \frac{\rho_{\phi,0}}{a^{3(1+w_\phi)}}$

$\downarrow$ dominant

$a \to 0$

1970: BKL instability "chaotic mixmaster" behaviour

$\rightarrow$ sol^{n}: ekp.^{c} ph., need $w_\phi > 1$ $\quad w_\phi = \frac{P_\phi}{\rho_\phi} = \frac{\frac{1}{2}\dot{\phi}^2 - V(\phi)}{\frac{1}{2}\dot{\phi}^2 + V(\phi)}$

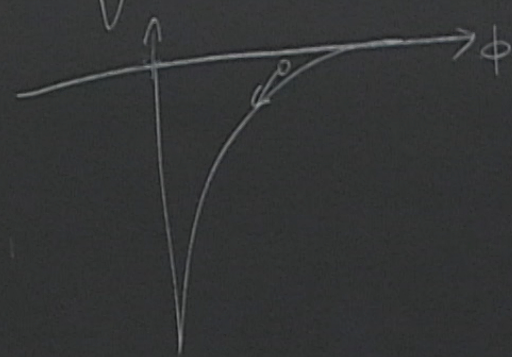
$$- \frac{3k}{a^2} + \frac{\rho_{m,0}}{a^3} + \frac{\rho_{r,0}}{a^4} + \frac{\rho_{\sigma,0}}{a^6} + \frac{\rho_{\phi,0}}{a^{3(1+w_\phi)}}$$

$\downarrow$

dominant

Typical pot.$^{\underline{\ell}}$

$$V(\phi) = -V_0 e^{-c\phi}$$



"chaotic mixmasters" behaviour

$w_\phi > 1$

$$w_\phi = \frac{P_\phi}{\rho_\phi} = \frac{\frac{1}{2}\dot{\phi}^2 - V(\phi)}{\frac{1}{2}\dot{\phi}^2 + V(\phi)}$$

−ve pot.$^{\underline{\ell}}$, steep, fast-rolling eom. $\ddot{\phi} + 3H\dot{\phi} + V_{,\phi} = 0$

ekp. ph = slow contraction

Friedmann $3H^2 = \frac{1}{2}\dot{\phi}^2 + V$

$a(t) = t_0(-t)^{1/\varepsilon}$ $\quad t \in [-\infty, 0^-]$

$\phi(t) = \sqrt{\frac{2}{\varepsilon}} \ln\left(-\sqrt{\frac{\varepsilon^2 V_0}{\varepsilon - 3}}\, t\right)$

scaling sol$^{\underline{n}}$

$\varepsilon = \frac{c^2}{2} = \frac{3}{2}(1 + w_\phi) \gg 3$

in Friedmann eqn each term scales like $\frac{1}{t^2}$

$H = \frac{1}{\varepsilon t}$ $\quad \dot{\phi} = \sqrt{\frac{2}{\varepsilon}} \frac{1}{t}$ $\quad V = -\frac{\varepsilon - 3}{\varepsilon^2 t^2}$

Flatness prob.

$$\Omega_k = -\frac{k}{(aH)^2} = 0.000 \pm 0.005 \quad (2\sigma,\ \text{Planck \& BAO})$$

Infl.

$$\Omega_k \propto \frac{1}{(aH)^2} \rightarrow 0 \text{ as } t \to \infty$$

grows rapidly; almost const

$a \sim e^{Ht}$ $\quad H \sim \text{const}$

Ekp.

$$\Omega_k \propto \frac{1}{(aH)^2} \rightarrow 0 \text{ as } t \to 0^-$$

almost const.; grows rapidly

$a \sim (-t)^{1/\varepsilon}$ $\quad H \sim \frac{1}{\varepsilon t}$ $\quad \varepsilon \sim O(10-100)$

Monopole Prob:

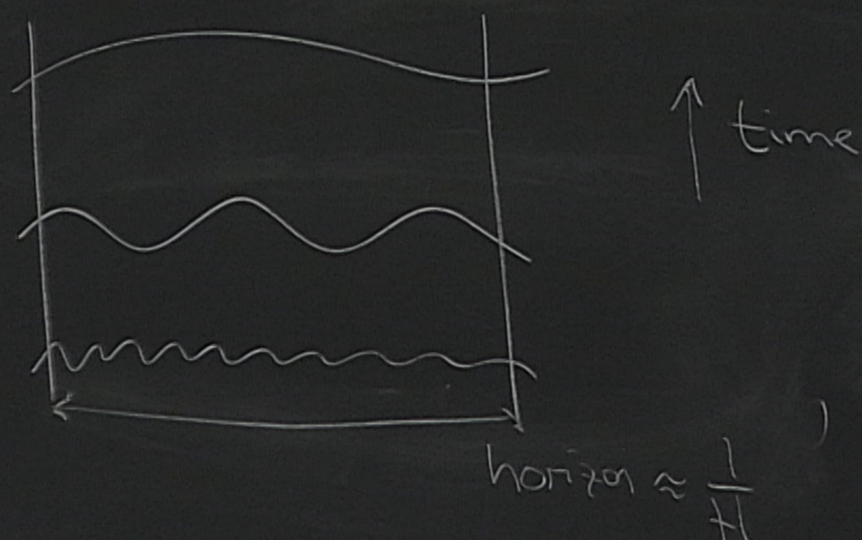
doesn't arise if $T_{bounce} < T_{GUT}$

Horizon Prob: enough time before bounce for distant regions to be in causal contact.

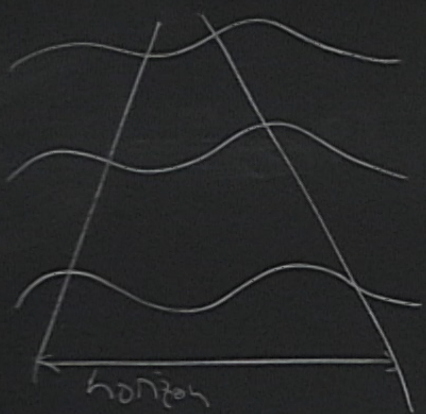
Cosmological Pert.$^{\underline{ns}}$

Heuristic picture

Infl.



Ekp

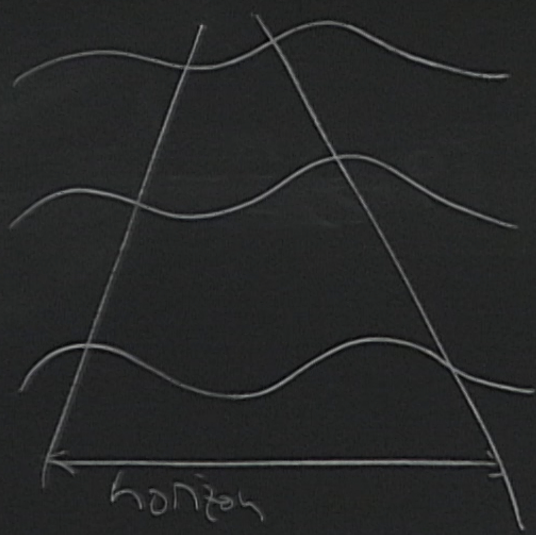


fluct$^{\underline{ns}}$ exit horizon,

become squeezed $\to$ stochastic distr$^{\underline{n}}$ of cl.$^{\underline{c}}$ dens. pert$^{\underline{s}}$

ekp $\to$ $n_s \approx 3$

Ekp



fluct.^{ns} exit horizon,

become squeezed → stochastic distr^{n}

ekp → $n_s \approx 3$

$$\phi = \bar{\phi}(t) + \delta\phi(t, x^i)$$

ADM $ds^2 = -N^2 dt^2 + g_{ij}(dx^i + N^i dt$

ζ gauge $\delta\phi = 0$ $g_{ij} = a(t)^2 \delta_{ij} (1+2$

horizon,

ed → stochastic distr.^{n} of d.^{c} dens. pert.^{n}

$= 3$

$) + \delta\phi(t, x^i)$

$- N^2 dt^2 + g_{ij} (dx^i + N^i dt)(dx^j + N^j dt)$

$\phi = 0 \quad g_{ij} = a(t)^2 \delta_{ij} (1 + 2\zeta(t,x))$ $\quad \zeta$.. comoving curvature pert^{n}

$$S = -\int \sqrt{-g}\,\varepsilon\, g^{\mu\nu}\,\partial_\mu \zeta\, \partial_\nu \zeta$$

in Fourier space in conf.^{e} time

$$(a\zeta)'' + \left[k^2 - \frac{a''}{a}\right](a\zeta) = 0$$

$$a\zeta = \frac{1}{\sqrt{2k}}\, e^{-ikt}$$

$$\langle \zeta^2 \rangle = \int \frac{d^3k}{(2\pi)^3}\, \zeta_k^*\, \zeta_k \sim \int \frac{k^2\, dk}{(2\pi)^3}\, \frac{1}{2k} \sim k^2 \sim P$$

$$n_s = 1 + \frac{d\ln P}{d\ln k} = 3$$

Monopole Prob

oesn't arise

if $T_{bounce} < T_{c}$